RESEARCH DEPARTMENT

THE SUBJECTIVE SHARPNESS OF TELEVISION PICTURES

Report No. T-065

(1957/1)

W.N. Sproson, M.A.

W. Proctor Wilson

(W. Proctor Wilson)

THE SUBJECTIVE SHARPNESS OF TELEVISION PICTURES

January 1957

Report No. T-065

(1957/1)

THE SUBJECTIVE SHARPNESS OF TELEVISION PICTURES

SUMMARY

The subjective sharpness of television pictures has been measured using a comparison technique and a multi-criterion scale for assessment. Two types of degrading network were used and the subjective sensitivity to changes in equivalent rectangular bandwidth has been evaluated for both static and moving pictures.

1. INTRODUCTION

This investigation was conducted in order to determine the subjective effect of reducing the definition of a 405-line television picture. The reduction of definition was achieved by causing the response of the picture-originating source to diminish with increasing frequency. This was done with either a sine-squared network[1] or a simple resistance-capacitance circuit. In the former case the effect is to cause a reduction of amplitude of the higher frequency components of the video waveform, without phase distortion. In the second case the amplitude and phase characteristics of the signal spectrum are both modified. The reason for selecting circuits which give a gradual loss of amplitude with increase of frequency is that this simulates the performance of a lens in respect of resolution, and the ultimate aim of these experiments is to produce a "figure of merit" for lenses when used as part of a television channel.

2. APPARATUS

The picture-producing device was a 35 mm flying-spot film scanner, which was used for producing moving pictures and also single frames of still pictures. The resolution of this picture source is very good in that the 3 Mc/s bars on Test Card "C" are reproduced with no visible loss of modulation. A laboratory monitor using a 15 in. (38 cm) cathode-ray tube was used as the display device. The response of the monitor has been measured and is within 0.5 dB of uniformity from zero frequency to 6 Mc/s. The picture-degrading networks were introduced before the gamma-corrector circuits in the film scanner, so that their effect should be analogous to that produced by a lens*. The amplitude/frequency characteristics of the sine-squared networks are shown in Fig. 1 and the characteristics of the RC networks are given in Fig. 2.

*Except that an electrical low-pass filter uniformly degrades the resolution in the direction of the scanning lines, whereas a lens affects the resolution also in the vertical direction, and varies in its effect over the field.

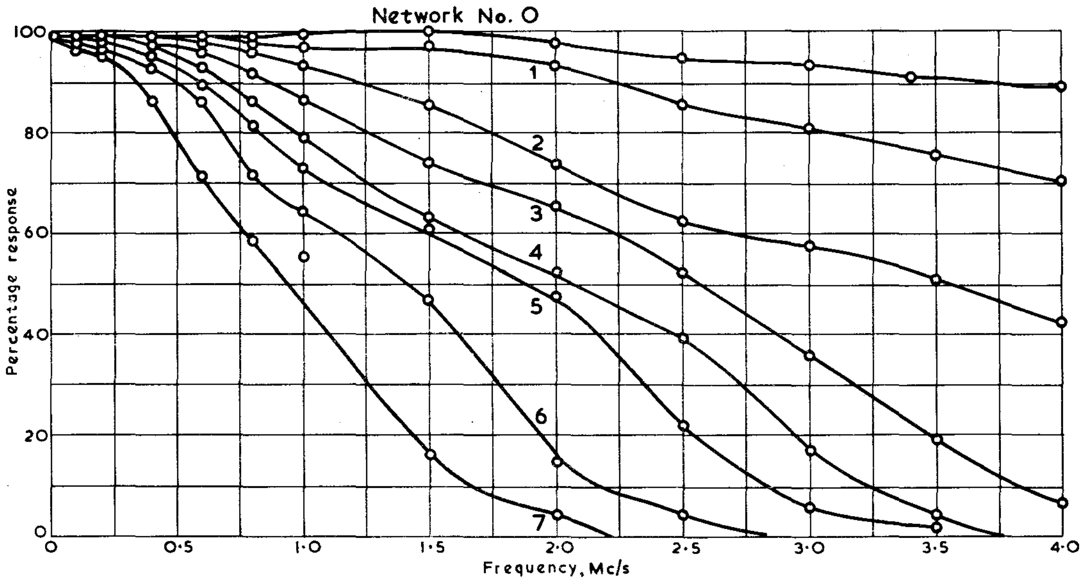

Fig. 1 - Amplitude/frequency responses of sine-squared networks

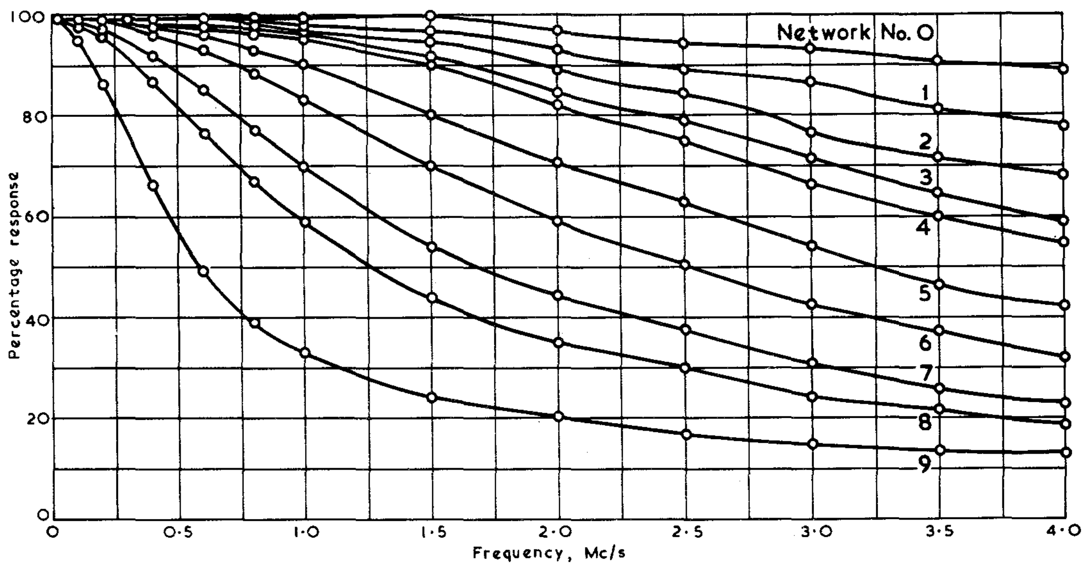

Fig. 2 - Amplitude/frequency responses of resistance-capacitance networks

3. METHOD

Five observers were seated in the arc of a circle at a distance of approximately four times picture height from the display monitor. The judgments were made in terms of a standard presentation of a picture which was not necessarily the best or the worst that could be produced. In every case the standard presentation of the picture was shown first and then an unknown presentation of the same picture, the observers being asked to state their opinion of the unknown in terms of the standard. Seven categories were allowed, including the category "about the same as". A copy of

the questionnaire is given in Appendix I. Seven different presentations were shown for a given standard presentation which was repeated each time: the observers were not expected to remember the sharpness of the standard. One session with five observers included four sets of comparisons (seven presentations in each) and thus involved 28 judgments for each observer. The pictures were presented in random order and a typical schedule is shown below:

Presentation Number	Set 1 RC Networks		Presentation Number	Set 2 "sin² Networks"		Presentation Number	Set 3 RC Networks		Presentation Number	Set 4 "sin² Networks"	
	Standard	Unknown		Standard	Unknown		Standard	Unknown		Standard	Unknown
1	3	6	1	5	4	1	6	8	1	2	6
2	3	0	2	5	7	2	6	5	2	2	3
3	3	5	3	5	5	3	6	6	3	2	1
4	3	4	4	5	1	4	6	3	4	2	4
5	3	1	5	5	3	5	6	9	5	2	5
6	3	2	6	5	2	6	6	7	6	2	0
7	3	3	7	5	6	7	6	4	7	2	2

The numbering of the networks is the same as shown in Figs. 1 and 2.

The results were evaluated by allocating the following scores:

Category	Much Sharper	Sharper	Slightly Sharper	About the Same	Slightly Less Sharp	Less Sharp	Much Less Sharp
Score	3	2	1	0	−1	−2	−3

4. RESULTS

4.1. Static Pictures

A typical result for one picture and three sessions (i.e. 15 observers in all) is shown in Fig. 3. This relates to the assessment of a static picture (street scene with building) in which the definition of the picture was changed by the use of sine-squared networks. The abscissa of the graph is the area under the response curve from zero frequency to 3 Mc/s and is proportional to the steepness at the point of 50% response with which a phase-linear system responds to unit step. Alternatively, we can regard the abscissa as the equivalent rectangular bandwidth*, normalised to a 3 Mc/s-wide rectangle. During each set of seven judgments, the standard picture was also shown as an unknown and this should give rise to zero score. Curve 1 of Fig. 3 crosses the axis at 0·83, which is in fact the sharpness factor of the standard picture. Curve 2 of Fig. 3 does not quite satisfy the condition as there is a small negative score for the standard picture when used as an unknown. Both curves in Fig. 3 show that the arithmetical sum of the scores corresponding to the judgments of the observers gave a close approximation to a straight line when assessed in this

* This is not the same as Schade's equivalent pass-band. Schade takes the area under the curve of squared ordinates. See National Bureau of Standards Circular 526, pp. 231-249.

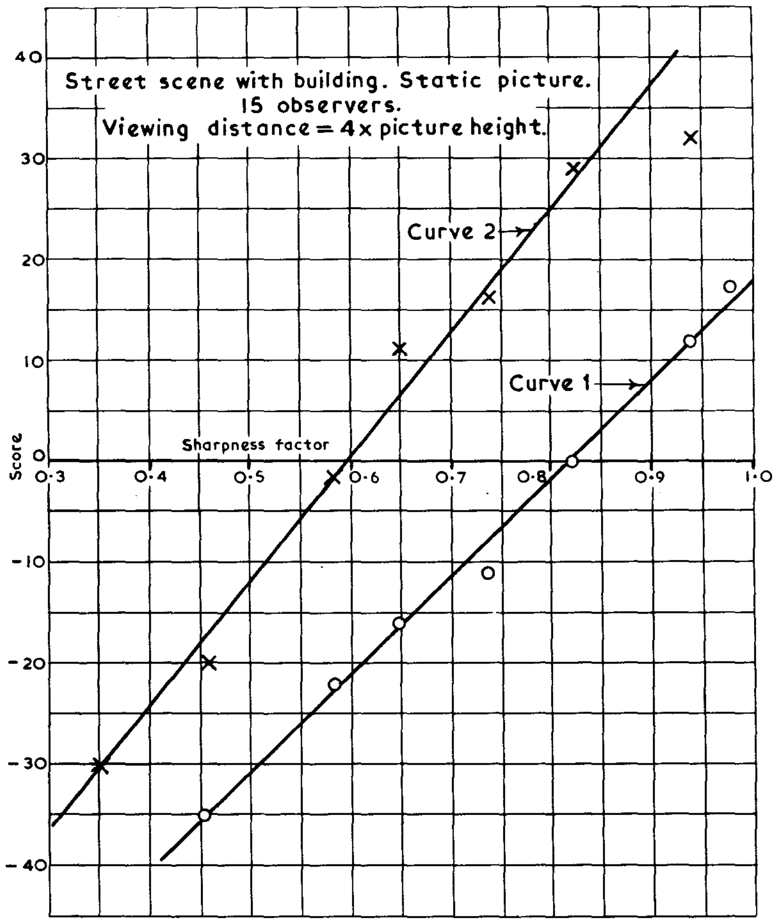

Fig. 3 - Subjective assessment using sine-squared networks

—o—o—o— Using comparison picture of sharpness factor 0·83
—x—x—x— Using comparison picture of sharpness factor 0·58

manner. This is not entirely surprising, as previous workers[2] have found that there is good correlation between the subjective sharpness of a picture and the gradient of the response to unit step at the mid-point of the transition. The correlation shown in Fig. 3 shows that television images are in the same category as optically formed images. The data from Fig. 3 enable us to quote a loss of bandwidth which is liminal in its effect, i.e. a change which 50% of the observers can perceive and of which 50% are unaware. Another effect which is apparent from Fig. 3 is that the slope of the curve relating score to equivalent bandwidth is a function of the sharpness of the standard comparison picture. Observers can more easily perceive a given change of equivalent bandwidth when the comparison picture is a relatively poor one: the slope of curve 2 is higher than that of curve 1. This effect was substantiated in all the tests undertaken. The gradients of the best* straight lines from several tests are shown in Fig. 4. Each point on the graph is the slope of a straight line from the results of three sessions (i.e. fifteen observers in all). The picture used for these tests was the street scene with buildings. In the case of a sine-squared degradation,

*Best in the statistical sense of minimum sum of squares of deviations.

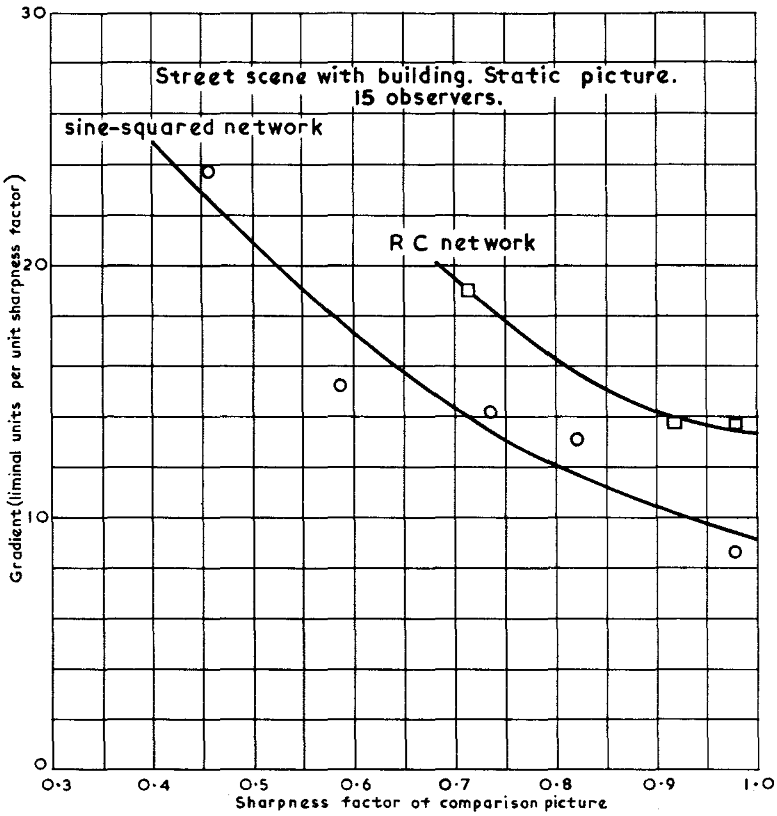

Fig. 4 - The effect of the sharpness factor of the comparison picture upon the subjective response to changes in sharpness factor

the gradient for a fully resolved 3 Mc/s picture (unit sharpness factor) is 9·2 liminal units per unit change in sharpness factor or, more significantly, 0·109 change in sharpness factor per liminal unit. This is caused by a change in equivalent rectangular bandwidth from 3·0 Mc/s to 2·67 Mc/s.

In the case of a resistance-capacitance network, the gradient at all points is greater and for a fully resolved 3 Mc/s picture its value is 13·5. This means that 1 liminal unit is produced when a 3 Mc/s picture is degraded to one with an equivalent rectangular bandwidth of 2·78 Mc/s. The human eye is thus seen to be more sensitive to losses which involve phase than to those which are phaseless.

It should be mentioned that the straight line correlation which is illustrated in Fig. 3 was found to exist for both sine-squared networks and RC networks with one exception, namely when the standard comparison picture was of low definition (sharpness factor = 0·45). The judgments of the observers plotted in the usual way gave a curved line for this case. This is illustrated in Fig. 5, which includes the information given in Fig. 3, and shows that although a straight line relationship holds for four of the sets of points, the set relating to a comparison picture of sharpness factor 0·45 is quite definitely curved. It would be pointless to try a change of parameter for the abscissa, as the excellent correlation which holds for all the other experimental results would then be vitiated. The straight line relationship which exists for almost all the experimental results cannot exist over a very

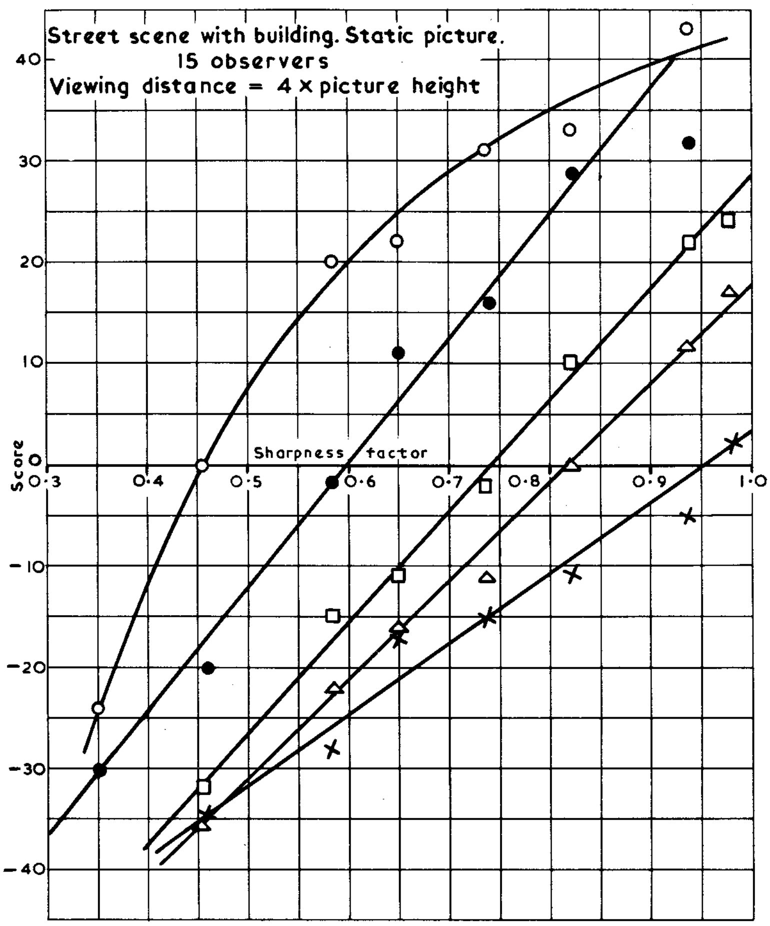

Fig. 5 - Subjective assessment using sine-squared networks

—×—×—×— Using comparison picture of sharpness factor 0·98
—△—△—△— Using comparison picture of sharpness factor 0·83
—□—□—□— Using comparison picture of sharpness factor 0·74
—●—●—●— Using comparison picture of sharpness factor 0·58
—○—○—○— Using comparison picture of sharpness factor 0·45

large range of values of equivalent bandwidth, as there will be a standard of picture in the high definition class for which the comment "much sharper" holds and beyond that no increase in score can take place however excellent the definition of the picture. Likewise in the opposite direction, a certain picture will be classed as "much less sharp" and any further reduction in equivalent bandwidth cannot alter the grading. Thus, the curve must become asymptotic to its maximum and minimum scores (± 45 in the case of fifteen observers). In spite of this, there does seem to be a considerable range of values for which a straight line relationship holds.

The question of picture astigmatism is of interest. The degrading networks affect resolution in the line direction only, so that the fully resolved 3 Mc/s picture (unity sharpness factor) is the only one in the United Kingdom 405-line system which is non-astigmatic. As the equivalent bandwidth is reduced, the picture must of necessity become astigmatic. Baldwin[3] has shown that over fairly wide limits the eye

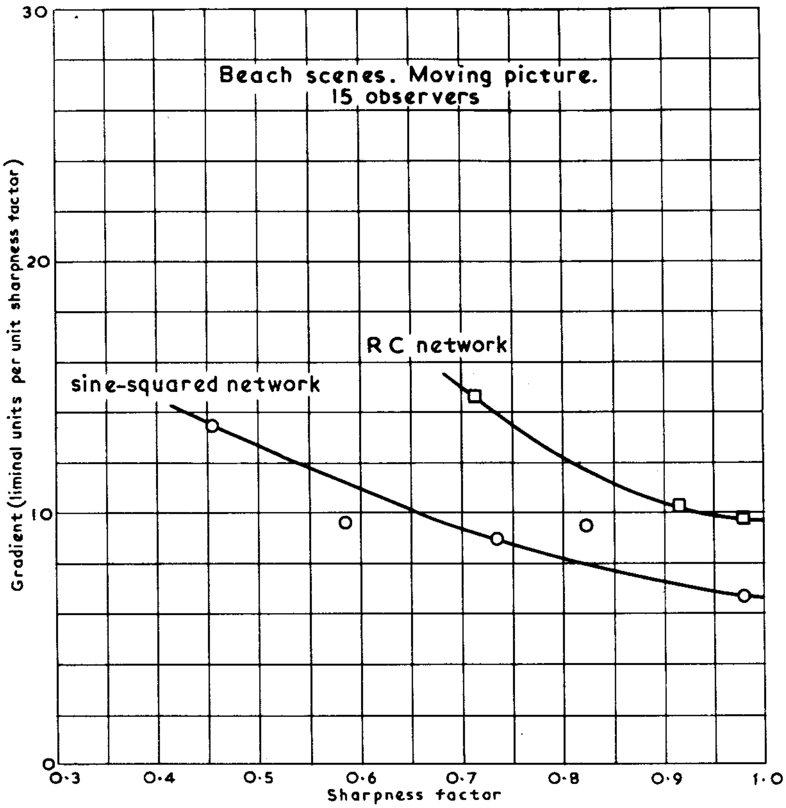

Fig. 6 - The effect of the sharpness factor of the comparison picture upon the subjective response to changes in sharpness factor

is not sensitive to picture astigmatism and as our limits are within those found by Baldwin, we shall make the assumption that our method of reducing the bandwidth does not seriously restrict the application of our results to cases where there is no astigmatism. This is certainly true in the vicinity of a fully resolved 3 Mc/s picture and most of the interest centres around this value, since we are concerned with the production of good 3 Mc/s pictures.

4.2. Moving Pictures

The type of scene and the presence or absence of motion might considerably affect the subjective judgment of sharpness. The scene used for all the tests described so far was a static frame from a 35 mm motion picture film and showed a considerable amount of detail. To extend the scope of the tests, a loop of 35 mm film was made up which had rapid movement in it: two beach scenes involving ball games were used for this purpose. The results from these tests were similar to those already described except that the gradients of the straight lines connecting score with sharpness factor were somewhat less. The correlation was still good (correlation coefficients greater than 0·9) and the case of comparison with a standard of sharpness 0·45 once more produced a curve and not a straight line. The gradients for a range of values of the sharpness of the standard comparison picture are shown in Fig. 6. The resistance-capacitance networks once more give higher gradients than the sine-

squared networks. For a fully resolved 3 Mc/s picture, the gradient for a phaseless degradation is 6·7 liminal units per unit change of sharpness factor: this means that 50% of the population can perceive a change in sharpness when the equivalent bandwidth is reduced from 3 Mc/s to 2·55 Mc/s. For a resistance-capacitance loss, the gradient is 9·7; one liminal unit corresponds to a change from a fully resolved 3 Mc/s picture to one with an equivalent rectangular bandwidth of 2·69 Mc/s.

Movement in a television picture is not always rapid. Another loop of film was therefore made up depicting Richard Dimbleby making an announcement. The movement in this loop was very restricted. The gradients for this subject were found to be intermediate between the static case when the subject matter was detailed and the moving case where the movement was at times rapid. It is considered that almost all practical cases will lie somewhere between the two cases just quoted, the results of which are given in Figs. 4 and 6.

5. DISCUSSION ON THE USE OF A MULTI-CRITERION SERIES OF JUDGMENTS

In describing the method, it was stated without explanation or justification that seven gradings were permitted for the observers to classify their reactions to the sharpness of an unknown picture in terms of a given comparison picture. Fundamentally there are only three categories in which an observer may place a picture, namely "sharper", "the same as", "less sharp". Nevertheless, degrees of comparative sharpness must exist, although there is no guarantee that different observers will mean the same thing when a given description is used. Hopkinson[4] has been using the multi-criterion technique in subjective studies for some considerable time and has shown that observers can maintain consistency and constancy over a period of time. His work was concerned with the assessment of glare conditions but the principles of multi-criterion assessment are probably of wide validity. Clearly, if too many categories are used, the attempt to secure more detailed information will be spoilt by the spread of opinions amongst the observers as to the precise meaning to be attached to a given phrase. On the other hand, it may be possible to obtain more information than is possible by restricting the categories to "better than" and "worse than". In the present instance, the "sharper" category has been subdivided into three — likewise the "less sharp" category. This measure of subdivision would not appear to be excessive and the good correlation between score and sharpness factor in the results is some evidence in favour of this. If the question asked is difficult or meaningless, a subjective experiment will give very low correlation between the score and the objective variable.

As a more precise check of this method of assessing results, the original data were classified into two categories only. The "about the same" judgments were divided equally into the two categories, "sharper" and "less sharp". The results were then plotted on arithmetic probability paper. The points so obtained in many cases (although not all) were capable of a straight line interpretation, and from the slopes of these straight lines the value of a liminal unit could be deduced. Fig. 7 shows one such plot and, in the table overleaf, the gradients of the best straight lines are compared on the seven-criterion and two-criterion bases.

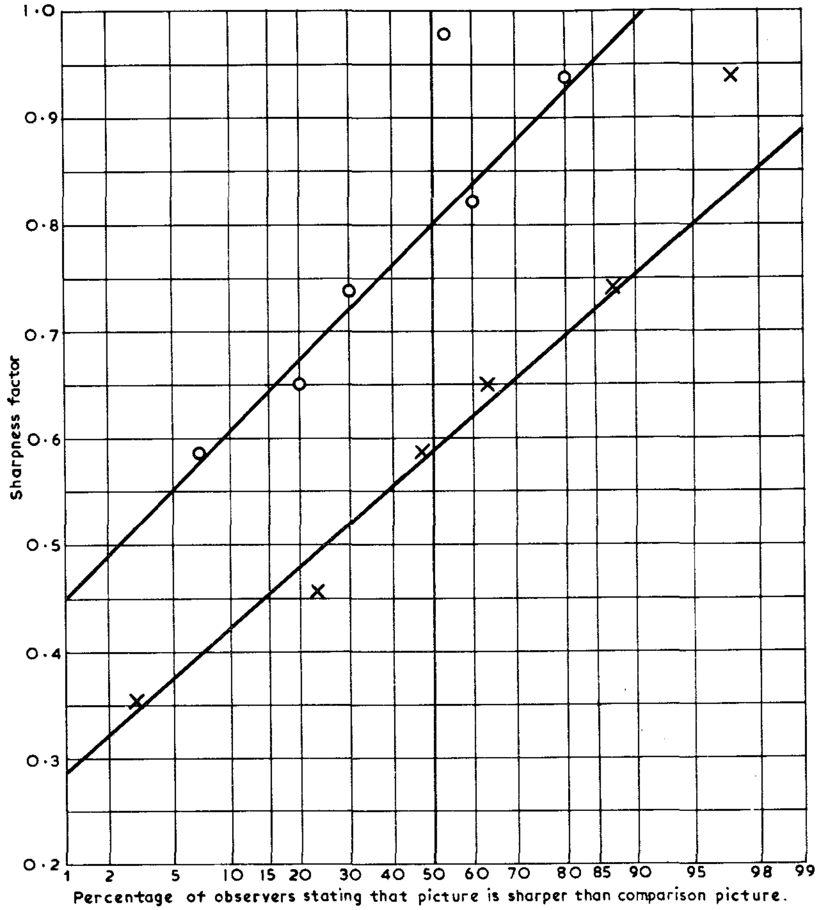

Fig. 7 - Assessment of sharpness using a two criterion scale

—×—×—×— Using comparison picture of sharpness factor 0·59
—○—○—○— Using comparison picture of sharpness factor 0·82

Apart from one or two exceptions, the two methods of assessment give very similar answers. One point of interest is that a probability scale cannot deal with complete certainty and in one case (viz. sessions Nos. 4, 5 and 6, comparison with picture through sine-squared network No. 6) we have this situation if the results are assessed on a two-criterion basis. Thus, when the picture was shown with sine-squared network No. 7, all fifteen observers stated that the unknown was less sharp than the comparison picture. When the picture was shown through network No. 5 all the observers agreed that the unknown was sharper than the comparison picture. Since 0 and 100% lie at minus and plus infinity on a probability scale the slope of the line cannot be deduced from this experimental evidence. The subjective change in sharpness between the pictures produced by networks Nos. 5 and 7 using No. 6 as a comparison is too great for this method of assessment. The seven-criterion method is in no such difficulty, since its multiple criteria permit various levels of certainty before the maximum or minimum score is reached.

The similarity of the gradients would appear to show that either method of assessment gives substantially the same answer, but there are conditions where the multi-criterion method gives more information.

COMPARISON OF GRADIENTS

Session No.	Standard Picture No.	7-criterion Assessment Gradient (limens/unit change of sharpness factor)	2-criterion Assessment Gradient (limens/unit change of sharpness factor)	Type of Degrading Network
1,2,3	2	13·1	13·8	$\sin^2$
	5	15·2	17·0	"
	2	13·7	15·5	RC
	6	19·0	20·6	"
4,5,6	0	8·6	11·8	$\sin^2$
	3	14·4	14·9	"
	6	23·7	–	"
	0	13·9	22·0	RC
7,8,9	2	9·5	9·8	$\sin^2$
	5	9·6	11·5	"
	2	10·1	12·7	RC
	6	14·7	10·2	"
10,11,12	0	6·7	5·5	$\sin^2$
	3	8·9	7·8	"
	6	13·3	7·8	"
	0	9·8	7·3	RC
13,14,15	2	10·7	9·8	$\sin^2$
	5	12·6	13·8	"
	2	11·0	14·2	RC
	6	16·4	19·7	"

6. APPLICATION TO LENS CHARACTERISTICS

Under the condition of a static picture containing much detail, a phaseless degradation has a gradient of 9·2 limens per unit of sharpness factor. This means that a 3 Mc/s picture will be degraded to the extent of 1 limen when the equivalent bandwidth is 2·67 Mc/s. It is not possible to quote a modulation (sine wave or square wave) at 3 Mc/s which is exactly related to this equivalent bandwidth, since the shape of the frequency/response curve must be known. It is possible, however, on the basis of many measurements of lens characteristics to say that, on the average, an equivalent bandwidth of 2·67 Mc/s is approximately equivalent to 89% square wave modulation at 3 Mc/s. If we have a lens giving 89% modulation over the whole of the field, its image will be 1 liminal unit down from the image produced by a lens which gives 100% modulation at 3 Mc/s. Certain figures have been suggested[5] for the performance of lenses for television. This appraisal of observer reaction to loss of definition shows that there is not a great deal to be gained by making lenses better than this figure, but the manufacturers have still some way to go before lenses in general have as good a performance as this. The axial modulation can (and often does) exceed 89% but the off-axis performance produces an integrated figure which is appreciably lower than this.

The case of the RC circuit is somewhat analogous to that of a lens having comatic aberrations. The response of an RC circuit to unit time impulse is markedly asymmetrical and the spatial response of a lens with coma is also asymmetrical. The degree of asymmetry from an RC network is in general greater than that of the residual comatic error in a lens, and hence the gradients quoted for RC circuits will, in general, be greater than is likely to be found with any high-grade lens. For general purposes, the gradient appropriate to the phaseless degradation can be applied to the whole field of a lens.

7. CONCLUSIONS

(1) The subjective assessment of sharpness is found to correlate well with the gradient of the response to unit step.

(2) The sensitivity to changes of equivalent bandwidth becomes less as the picture quality improves, i.e., for a liminal unit of improvement of picture quality, a progressively greater increment of bandwidth is required as the picture sharpness increases.

(3) The eye is less sensitive to loss of amplitude which is phaseless (or phase-linear) than to a loss of amplitude associated with a non-linear phase characteristic.

(4) Under the optimum conditions of viewing and with a scene containing much detail, 1 liminal unit corresponds to a phase-free change in equivalent bandwidth from 3 Mc/s to 2·67 Mc/s.

8. REFERENCES

1. Thomson, W.E., "The Synthesis of a Network to have a Sine-Squared Impulse Response", Proc. I.E.E., Vol. 99, Part III, pp. 373-376, November 1952.

2. di Francia, G. Toraldo, Atti Fond. Ronchi, Vol. 7, p. 107, 1952.
   Higgins, G.C. and Jones, L.A., "The Nature and Evaluation of the Sharpness of Photographic Images", Journ. Soc. Motion Picture and Television Engineers, Vol. 58, p. 277, April 1952.

3. Baldwin, M.W., Junr., "The Subjective Sharpness of Simulated Television Images", Bell System Technical Journal, Vol. 19, p. 563, October 1940.

4. Hopkinson, R.G., "The Multiple-Criterion Technique of Subjective Appraisal", Quarterly Journal of Psychology, Part III, Vol. 2, p. 124, 1950.

5. B.B.C. Research Department Technical Memorandum No. T.1015, "The Performance of Lenses for Television".

APPENDIX I

PICTURE SHARPNESS TESTS

Assess the unknown in terms of the standard comparison picture.

		Sharper				Less Sharp		
		Much Sharper	Sharper	Slightly Sharper	About the Same	Slightly Less Sharp	Less Sharp	Much Less Sharp
	1							
	2							
	3							
Set 1	4							
	5							
	6							
	7							
	1							
	2							
	3							
Set 2	4							
	5							
	6							
	7							
	1							
	2							
	3							
Set 3	4							
	5							
	6							
	7							
	1							
	2							
	3							
Set 4	4							
	5							
	6							
	7							

APPENDIX II

Subjective Effect of Phase Change without Loss of Amplitude

Although lenses produce some loss of amplitude (with or without phase distortion) it is an interesting case to consider an electrical network of the all-pass type, such as to give a constant amplitude response but group delay increasing with frequency (up to about 3 Mc/s). A series of such all-pass networks was constructed with group delays of approximately 0·1, 0·2, 0·3 and 0·4 μs delay at 3 Mc/s. The group delay characteristics are shown in Fig. 8. By adding several networks, group

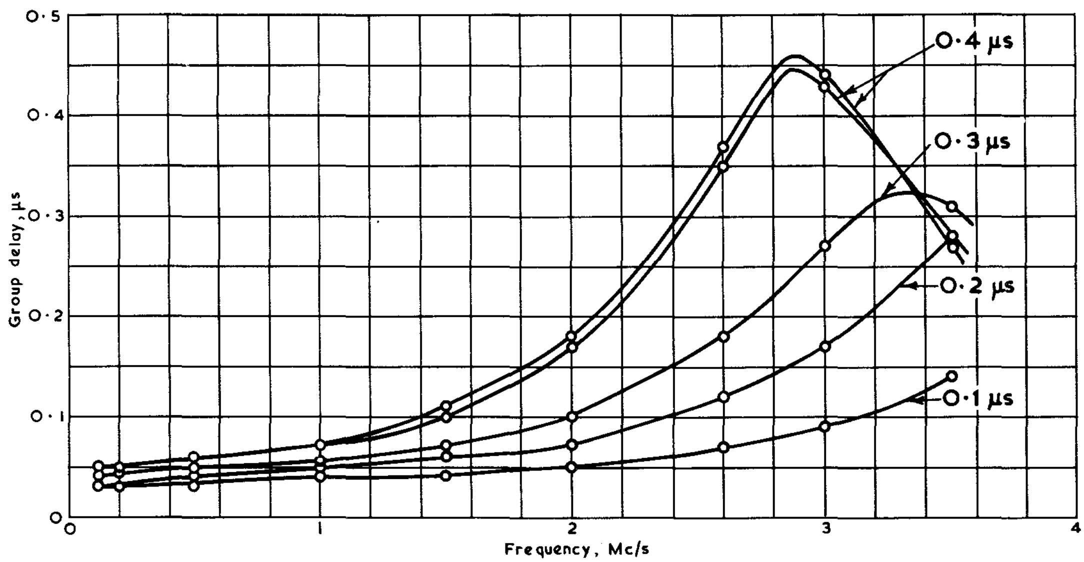

Fig. 8 - Group delay characteristics of all-pass networks

delays up to 1·4 μs may be obtained. The effect on the picture is to produce more or less pronounced "rings" — although the amplitude/frequency characteristic remains unaffected. Hence one cannot question observers in this instance about the sharpness of the picture. The wording of the questionnaire was altered to "better" and "worse" and, as before, each of these two categories was subdivided into three. A very similar experimental technique was used and a typical result is shown in Fig. 9. The score is plotted against the group delay at 3 Mc/s. The "goodness-of-fit" to a straight line was quite as good as in the previous experiment and correlation coefficients of values greater than 0·9 were nearly always obtained. The effect of the group delay of the standard comparison picture on the gradient is shown in Fig. 10. This graph shows a maximum sensitivity for a comparison picture with a group delay of approximately 0·4 μs when the viewing distance is approximately four times picture height. Thus, from 0 to 0·4 μs the effect on the gradient is not unlike that found for change of bandwidth, viz., the eye becomes less sensitive to a given change as the quality of the picture improves. For a group delay exceeding 0·4 μs, the gradient becomes less and this may be due to the fact that we are considering pictures containing many "rings" so that a slight change in the "ringing" is not as noticeable as when the picture is fairly free from "rings". In this respect, phase errors do not

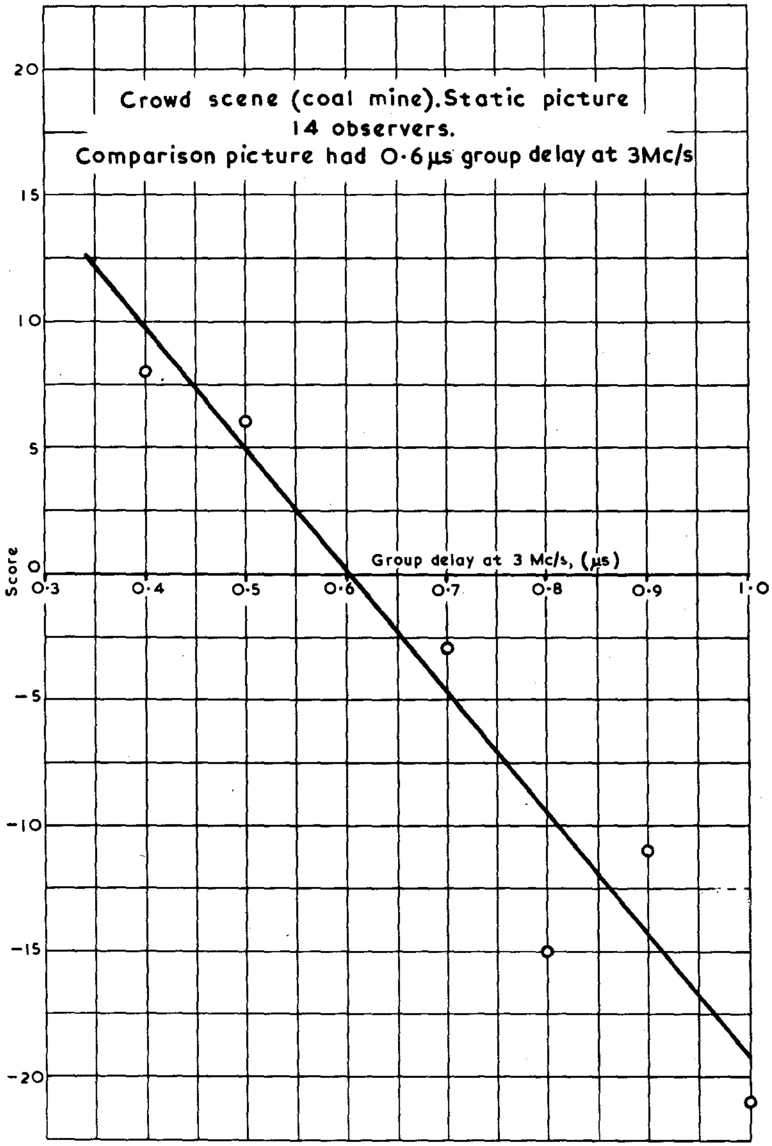

Fig. 9 - Subjective assessment of picture quality using phase distorting networks

produce the same effect as loss of bandwidth, where the gradient continues to increase as the equivalent bandwidth is reduced (Figs. 4 and 6). The position of the maximum shown in Fig. 10 would appear to depend on viewing distance. A repeat of the experiment with the observers placed at eight times picture height gave gradients of very similar magnitude (in the range 5 to 7 liminal units per μs) but the peak value now occurred for a group delay exceeding 0·7 μs if a peak still existed. The results of this experiment are shown in Fig. 11.

Restricting our interest to the region of good pictures, we can summarise the results by saying that a group delay of about 0·2 μs at 3 Mc/s produces the subjective effect of one liminal unit, i.e. 50% of the population can just perceive a change and 50% regard the picture as unchanged.

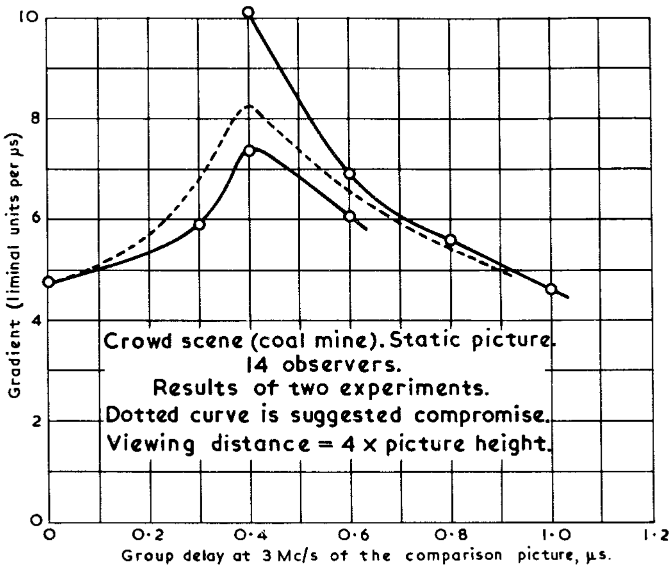

Fig. 10 - The effect of the group delay of the comparison picture on the subjective response to changes in group delay

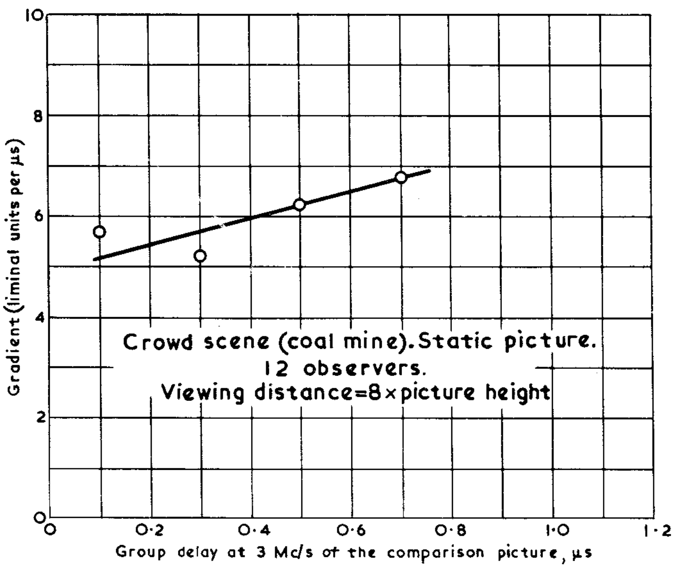

Fig. 11 - The effect of the group delay of the comparison picture on the subjective response to changes in group delay